1 Titan Airship Explorer

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Abstract – Saturn's moon Titan is considered as one of prime candidates for understanding the origins of life A unique combination of dense atmosphere (more than four times that of the Earth), low gravity (six times less than on the Earth) and small temperature variations makes the Titan almost ideal for studies with with aerobots. Moreover, since the methane clouds obscure all the surface the aerial platforms are the only means that can provide high-resolution global mapping the Titan surface at least in visible and infrared. The major challenge is extremely cold atmosphere (~ 90K). Remoteness from the Sun and obscuring cloud cover makes the nuclear energy the only practical source of power. Remoteness from the Earth (~10 A.U., two-way light-time ~160 min) imposes restrictions on the data rates and makes impractical any meaningful real-time control. Powered aerobot (airship) in different modifications is prime lighter-than-air (LTA) platform. The aerobots can be used for *in situ* studies of the surface while landing ("aerover") or winching down an instrumented surface platform (powered aerobot).
The airship will use electric drive propeller and autonomous/Earth assisted control for access to a desired destination point. Airship point design is provided. Requirements and possible means of navigation, control, data

acquisition and communications are discussed. The airship can be a good candidate for the post-Cassini exploration of the Titan [1].

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1. INTRODUCTION

Saturn's moon Titan (see [2]) has some common features with the planet Venus. Both have dense deep atmospheres, both have small thermal contrasts, both are completely covered with clouds and both are slowly rotating that suggests a probability of unusual circulation pattern of their atmospheres (which as we know is the case of Venus). Temperaturewise, Venus and Titan are on extremes: Venus is on the hot side, Titan – on the cold.

Exploration of the Saturn's moon Titan may follow the pattern of exploration of Venus: first remote single pass by the fly-by Voyager spacecraft, then a single point probing of atmosphere in the Huygens-Cassini mission, then possible orbiter to get global coverage and mobile *in situ* probes which will study large areas of the planet.

Solar ultraviolet light and energetic particles in the Saturnian environment break down methane and nitrogen in Titan's upper atmosphere to produce a host of complex organic molecules, of which over 20 have been identified in infrared spectra. These molecules form a thick orange haze which gives Titan its color. These compounds sediment out onto the surface where they may form thick deposits. Where these organics have interacted with transient exposures of liquid water (e.g. in impact melt sheets on Titan's ice surface) more complex prebiotic molecules including amino acids may be formed ([3]).

Detailed long-term studies of large areas of the surface (topography, surface structure, mineralogy, chemistry and composition), subsurface (structure and high-resolution magnetic field) and atmosphere (winds, composition, vertical structure, variations atmosphere and surface would be of ultimate interest for the next generation mission to Titan. As at any planet with atmosphere, interaction between atmosphere and surface is of prime interest; it is even more true in case of Titan where pre-biotic materials likely are formed in the atmosphere and then deposits on the surface.

Mobility and endurance will be one of prime criteria for selecting future vehicle for in situ exploration of Titan. The frozen surface of Titan could be quite odd – it may be a combination of hydrocarbon ocean (s) with rugged water ice, rocks etc. It is unlikely that conventional rovers can do anything there without preliminary intensive characterization of surface. On the other hand, dense atmosphere and low temperature contrasts makes Titan almost an ideal planet for aerial vehicles. In the last years authors studied different types of them: heavier-than-air (HTA) – airplanes and helicopter ([1,4]) lighter-than-air (LTA) – aerobots and airships ([5,6]), and hybrid vehicles – "aerovers" which could combine properties of both HTA and LTA ([7-10]) . Science requirement of surface sampling implies landing and associated risks for airplanes and helicopters, the latter also require unmanageably aggressive power-to-mass performance from a nuclear power system leaving LTA vehicles – primarily powered aerobots (airships) and aerovers the most likely candidates for the next mission to Titan. Presently the aerover concept evolved to the modification of airship with additional devices for landing and vertical control [11]. The example of airship point design presented in this paper demonstrates the main features of the LTA approach and gives an idea about main systems and problems for a wider range of vehicles.

2. TITAN ENVIRONMENT

Titan's equator is inclined to the ecliptic by 27 degrees, a similar amount to the Earth, so Titan has a seasonal cycle, albeit rather slower during the 29.5 years it takes Titan to go around the sun. Titan rotates synchronously about Saturn, always with the same side facing its parent, and thus the diurnal cycle on Titan is 15.45 days long.

Titan's radius is 2575km (between the Moon and Mars in size) and its density of 1.88 kg/m3 suggests it is roughly half rock and half ice – with the rock probably concentrated into a core. The surface gravity is 1.35 kg/m^3, similar to that on the Moon and is less than 1/7 of the Earth's value.

Titan's cold atmosphere is quite dense. The surface pressure is 1.5 bar, and at 94K has a density of 5.3 kg/m^3. Temperature falls slowly with altitude towards the tropopause at 40km and a temperature of 72K. Surface temperatures drop towards the poles by around 3K The view of the sun is significantly dimmed and blurred by the thick haze layers (concentrated between 80 and 200km altitude). Scale height of the atmosphere is approximately 22 km *vs.* 8 km on the Earth and pressure (and density) decrease significantly slower (Fig. 1).

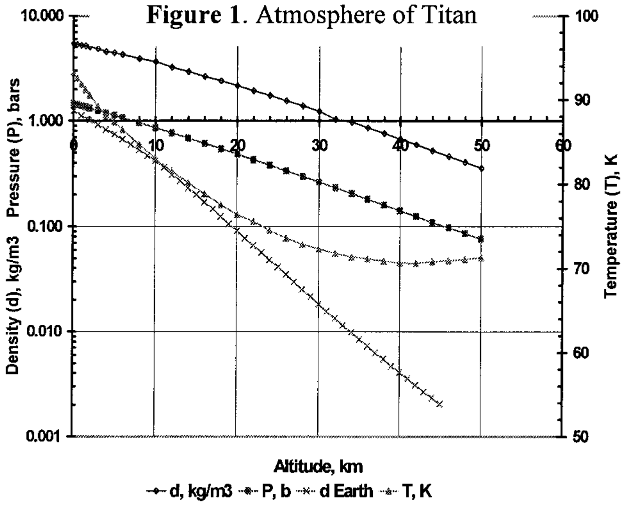


Figure 1. Atmosphere of Titan

The principal component of Titan's atmosphere is molecular nitrogen, with methane the next most abundant component with a mixing ratio of around 2% at the tropopause (where, like water vapor in the Earth's atmosphere, it is cold-trapped). At lower altitudes, methane may be up to about 6% abundant. Titan's atmosphere is too cold for oxygen-bearing compounds (like CO_2) or ammonia to be present in anything more than trace quantities. Methane may condense to form rain near the surface, while above altitudes of 5-20km (depending on latitude and meteorological factors) it would form clouds of ice crystals. Accordingly air vehicle operations should be restricted to near the surface.

Data on Titan winds are scarce. In the free atmosphere of Titan winds are believed to be in the cyclostrophic balance with meridional pressure gradient (as on Venus) and predominantly zonal [12-14]. Wind velocities of tens meter/sec are expected in the free atmosphere. Winds are small near the surface. Linear increase from 0 to 5 m/s at altitude 4-5 km seems a reasonable assumption based on the available data.

Titan's icy surface is heterogenous, as seen in maps from the Hubble Space Telescope (which in the near-infrared was able to penetrate the thick haze layers, unlike the wavelength-limited cameras of Voyager 1) . The heterogeneity is likely an indication that while some regions are 'clean' water ice, other areas are covered with organic material – deposits of haze, and also ethane (the main product of the breakup of methane by UV). Ethane, like methane, is a liquid at Titan surface temperatures and may well form lakes and seas on Titan's surface, making Titan an excellent laboratory to study "cryometeorology" and "cryooceanography" as well as prebiotic chemistry.

3. Titan Airship Explorer Mission Concept

At this stage we assume that the most of the science objectives could be met with the science payload of mass 20-30 kg of 2005 technology (compare to 44 kg of the Huygens probe science payload designed in 70-80s). A relatively small airship of approximately 100 kg total floating mass can accommodate this payload. Though no serious spacecraft mission design was attempted, it is supposed that such airship with associated systems can be delivered in a moderate mass entry vehicle (EV) of order 300-350 kg (Huygens probe mass is 320 kg). The aeroshell can be optimized for size and mass since there is no requirement on high-altitude deployment of parachute (the Huygens probe has large 2.7 m diameter aeroshell to meet the science requirement to start measurements at 160 km altitude).

After the launch and 6-7 years of interplanetary cruise the EV with the packed airship, inflation system and payload will be inserted in the atmosphere of Titan. The direct insertion to the atmosphere could be a mass-optimized option. The carrier spacecraft can perform aerodynamic capture maneuver to become a Titan's orbiter.

After deceleration with the aeroshell and 20-40 min of subsequent free fall, a 40-50 m^2 subsonic parachute will be deployed at altitude 3-5 km above the surface. The descent will continue to 1.0 -1.5 km – below the nominal float altitude of the airship. Descent velocity 2 m/s (aerodynamic pressure ~ 8Pa) provides Earth-proven environment for a risk-free airship deployment and inflation. The airship will be deployed from the entry vehicle; the ripstitch shock absorber and internal load line will be used to attenuate the deployment loads on the airship hull. Firing of the pyrovalve will initiate helium flow from high-pressure tanks suspended under the airship; the airship inflation will take 3-5 min. After that, first the parachute and then the inflation system will be released to initiate a free flight of the airship and beginning of its science mission.

4. Airship Point Design

A 100-kg of total floating mass airship with 20-30 kg of science payload could be a representative example of the concept. A 75 kg total payload will accommodate all systems. Float altitude of the airship has to be 0.5-4 km to prevent possible methane icing and stay at the low wind area of the atmosphere. An airspeed of 2-5 m/s will make possible directed flight to any point of the planet, hovering or landing for *in situ* studies of the surface. Capability of vertical control in range 0-4 km will provide sufficient clearance to avoid any obstacle on the Titan's surface, perform landings and take-offs on/from possible ethanol lakes and use winds to move along .

To make global survey, conduct surface studies in multiple location and gather sufficient data on the Titan meteorology the lifetime of the airship should exceed a year.
Even without use of winds such airship in a year may cover 60,000-300,000 km along Titan surface and may encompass it 4-15 times.

We'll describe now possible airship design. Dense atmosphere ensures high payload mass fraction and provides enough of room for optimization of the hull shape and materials.

One of the main properties required for the envelope material is operation without brittleness at Titan's temperatures. The material should also retain impermeability after being tightly packed inside the entry vehicle during 6-7 years of cruise flight; it also should withstand loads during deployment from the entry vehicle.

The low temperature requirements make the selection of materials and seaming technology very challenging. However, there are a number of possible films and fabric candidates. The list of film candidates includes Mylar, polybenzoxazole (PBO), polyimides (Kapton), fluorinated (Teflon) polymers, etc. Possible fabric material candidates include polyesters (Vectran, Dacron), polybenzoxazole (Zylon), fluorinated polymers and others. A composite material made from a light weight fabric coated with a polymer resin could be a very good choice. An example of a composite material would be a PBO fabric coated with polyamic acid which is then cured and converted to polyimide. Another example would be a fluoropolymer coated PBO fabric. The feasibility of such composite films has been demonstrated on a laboratory scale in JPL. The use of composite materials may offer an advantage in the development of seaming schemes. Fabrics allow sewing for the fabrication of the blimp envelope, whereas the use of plain polymer films will require finding adhesives, which might be a significant challenge at these low temperatures. Areal density of the material 100 g/m^2 can be a realistic assumption for a point design of the airship.

The airship should have an aerodynamically shaped envelope to reduce aerodynamic drag and ensure the horizontal trajectory control. Finesse ratio (ratio of length to diameter) 4:1 is adequate for a low-drag shape at the expected range of flight Reynolds number (Fig.2, see also [15]).

Application of buoyancy equation to the 4:1 ellipsoidal hull made of material with areal density 100 g/m^2 to float 75 kg payload at 4 km above the surface resulted in diameter 2.1 m and length 8.4 m if helium used as buoyant gas. Total mass of the airship body that includes fittings and fins would be approximately 10 kg.

Nitrogen of Titan's atmosphere is lighter than carbon dioxide of Venus and Mars and buoyant gas is less effective on Titan than on Mars or Venus. Such airship would require 13.6 kg of helium to be afloat. Use of hydrogen would provide significant mass saving and increase payload by 7.3 kg i.e. by 10% since only about 6.3 kg of gas will be needed. Use of hydrogen can be considered as an additional payload mass margin.

5. Propulsion and Power System

The power system is one of the key components for the successful operation of the Titan Airship. This power will be used for the propulsion system, onboard electronics and payload. Power estimates for each of these systems or components will have to be determined in order to select and size the power system.

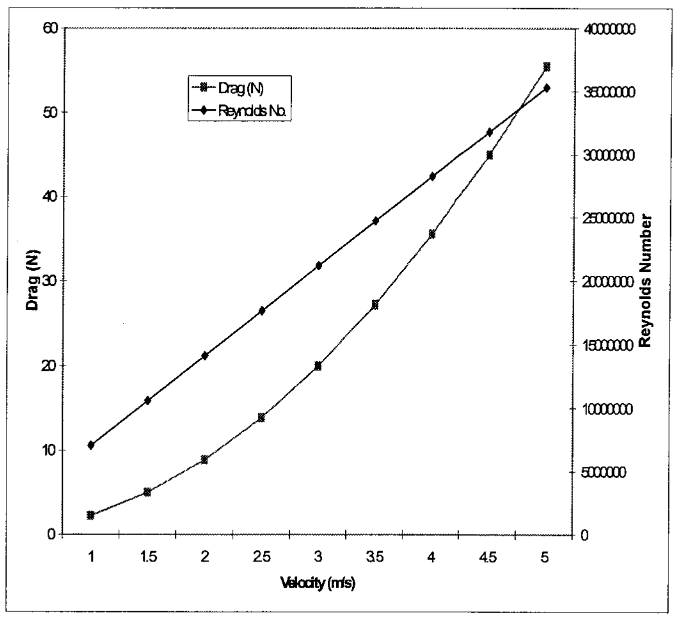


Figure 2. Flight Reynolds number and drag at various velocities

The power required by the propulsion system, which will comprise a majority of the power demand, is based on the desired flight speed and corresponding drag of the airship. The Reynolds number as a function of flight velocity for the 2.1 m diameter airship is shown in Figure 1. The Reynolds number is based on a flight altitude of 0.5 km. This corresponds to an atmospheric density of 5.34 kg/m^3 and a kinematic viscosity of 1.189E-6 m^2/s.

Based on this Reynolds number the flow will be turbulent over a portion of the vehicle. For turbulent flow an ellipsoid geometry it is estimated the vehicle will have a total drag coefficient (form and skin friction drag) of approximately 0.24. This is based on a turbulent drag coefficient of 0.15 for a two dimensional elliptical cylinder with a fineness ration of 4 and a $\pi/2$ ratio between the drag of a three dimensional ellipsoid to a two dimensional ellipse [16,17]. The drag force for a given flight speed is also shown in Figure 1. Optimization of the airship shape can reduce the drag of hull itself down to 0.02-0.03 ([15]). However we'll use the previous values as conservative estimates since payload gondola and fins will increase drag of airship above the optimum value.

The power required for the propulsion system is based on the requirements of the propeller to produce enough thrust to overcome the drag. For a flight speed of 3.5m/s the thrust requirement is 32 N. To meet this thrust requirement a 4 bladed propeller 0.8 m in diameter was used. A design point for the propeller and an estimate of its performance is shown in Figure 3. The propeller utilized a SD-8000-PT airfoil and twisted blade with 10° blade angle at the 3/4 radius station. For packaging convenience the blades can be folded.

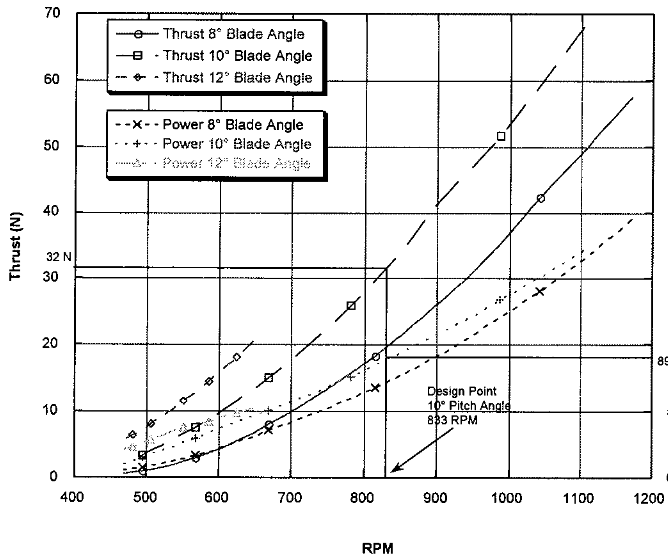


Figure 3. Design point for a four bladed propeller 0.8 m in diameter

For the propeller to produce 32N of thrust it requires 89 W of shaft power and a rotational speed of 833 RPM. This translates into an operational efficiency of 89% at this design point. Off design operation (either flying at a different speed or at at different altitude) will decrease this efficiency value. However, operating at a reduced efficiency can be compensated for by flying at a slower speed which, as shown in Figure 2, reduces the required thrust and therefore power.

The power system selected for the airship must be capable of meeting the power demands of the various systems as well as being able to operate within Titan's environmental conditions. Because of the great distance Titan is from the sun the solar intensity is only 14.87 W/m^2 that eliminates solar power as an option. The power system that makes the most sense for this application is a dynamic isotope system. This system does not require any fuel, and the waste heat provides a heat source for the other airship's systems. Also the dense atmosphere and low temperature are ideal for minimizing the radiator size for rejecting any waste heat from the system. A Stirling isotope system would be the best choice for this application due to the relatively low power levels needed. A 55 W system is being developed at the NASA Glenn Research Center (Figure 4) and would be ideal for this application [18-21].

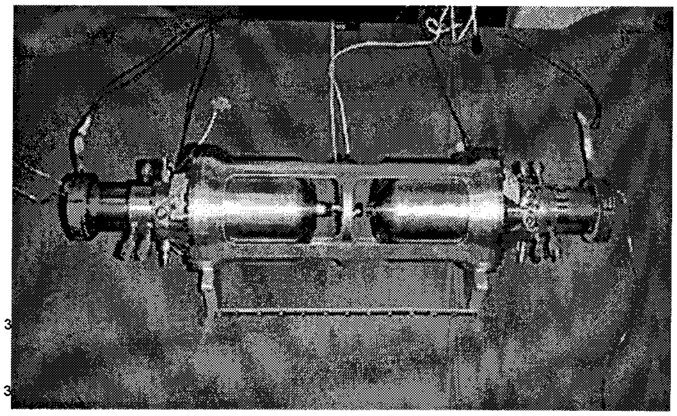
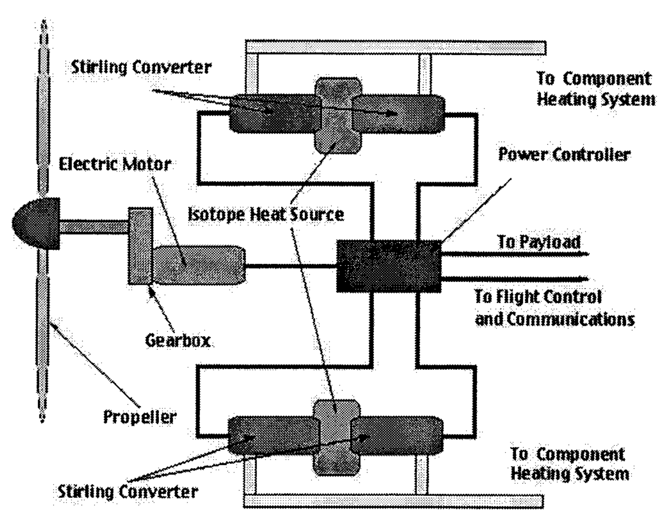


Figure 4. 55 W Stirling Engine [21]

Operating at a temperature difference between the heat source (650°C) and the heat sink (80°C) of 570° C the engine was capable of producing 65 W of power with a direct thermal to electrical conversion efficiency of 27%[22]. The temperature difference on Titan will most likely be greater then this due to the very cold atmospheric temperature. Therefore two such converters would provide on the order of 130 W of power, 105 W would be used for propulsion (assuming a drivetrain efficiency of 85%) and the remaining 25 for flight systems and payload requirements. By utilizing two converters, development cost is reduced and the mission reliability is increased. Two converters provide a level of redundancy for the mission. If one converter fails there will still be power available to continue the mission at a reduced level. If the communications or experiments require more power for short duration the propulsion motor can be shut down or scaled back providing up to the full 130 W for these systems.
A diagram of the power and propulsion system is shown in Figure 5.



Presently the Stirling power system (including the converter and isotope heat source) has a specific power of greater then 4 W/kg. It is estimated that this specific power can be increased to 6 W / kg through proposed near term development work [22]. For a 130 W system this would produce approximately 350 W of heat that would need to be removed from the system for it to operate. This heat can be utilized to warm the electronics; otherwise, the radiator size to remove the total 350 W of excess heat is on the order of $0.1\ m^2$ for a conservative radiator heat transfer coefficient of 4.18 W/ m^2 °K.

A breakdown of the power and propulsion system component masses is given in Table 1. It was assumed that the blades were constructed of carbon composite (1350 kg/ m^3). The electric motor is based on a typical model aircraft high performance brushless DC motor operating at the power level specified above. The power controller mass is based on the motor power level and an estimate of the wiring needed to connect the various propulsion and power system components.

Table 1 Power and Propulsion System Mass Breakdown

Component	Mass (kg)
Propeller	2.32
Motor / Gearbox	~2.00
Stirling Converter with Heat Source	18.33
Power Controller and Wiring	~1.50
Heat Transfer Material	~1.0
Total	25.15

6. Vertical Control

Big height scale of the atmosphere ($R_oT/\mu g$=22 km) makes easier vertical control of the airship: change of lift by 16% would change the airship altitude by 4 km. A traditional ballonet (secondary internal gas bag filled with ambient gas by a blower) can be used efficiently. Near the surface the ballonet is filled with ambient gas. When the airship moves up the buoyant gas expands and pushes "air" out of the ballonet. At the maximum float altitude the airship is filled completely with the buoyant gas. When the airship moves down the buoyant gas contracts and a blower fills the ballonet to preserve the airship shape intact. Combination of ambient gas blower and valve for ballonet, fins and vertical vectored trust motor can be used to control precisely vertical motion of the airship.

Additional control can be done using a portion of waste heat from the isotope heat source to change buoyancy by heating gas inside the bag. Preliminary analysis has shown that if 200 watts of radioactive power source (PRS) waste heat is diverted into the bag by means of a variable conductance heat pipe, an additional 3 kg of lift can be attained for operation on Titan. This should normally be enough to allow the blimp to ascend to some specified altitude without any power.

When landing the vehicle, the waste heat can be diverted to outside the bag, and the vehicle will descend to the surface of Titan.

For in situ surface studies two approaches could be considered: landing of the airship itself or winching down the surface instrument package. A large floatation wheel centered below the center of gravity can then serve as a landing and mobility wheel for both solid and liquid surfaces.

Interestingly that if the payload could operate in liquid ethanol the airship can land on a liquid ethanol lake without any additional device and use its propellers for motion. 150-200N of lift provided by ballonet would be sufficient for take-off.

7. Navigation and Communications

Floating at the low altitude for a year, the airship can produce a huge amount of high-resolution imaging, radar, spectroscopic, magnetic and other types of data. Capability of the space-to-Earth down link is the factor that will limit the data volume. Airship can maintain a stable vertical orientation that would enable use of high-gain tracking antenna. Link budget for direct-to-Earth communication is given in Table 2.

Table 2. X-band link budget

X-band transmitter power, W	10
Antenna diameter, m	0.8
Antenna beam angle, deg	3.1
Antenna gain, dB	34.4
Range, AU	10.5
Space losses, dB	-294.9
Misc. losses (diplexer, atmosphere etc), dB	-0.8
Receiving antenna diameter, m	70
Receiving antenna system temperature, K	21
Data power/N_0 (modulation index 90°), dB*Hz	38.2
Bit rate, bit per sec	2000
Threshold, dB	1.9
Margin, dB	3.3

For direct-to-Earth link a 0.8-m diameter airship antenna with 10 W X-band transmitter may transmit over 2000 bit/sec (or 10.8 Mbytes per 12 hrs) to the DSN 70-m antenna receiving stations. This amount is equivalent to 100-200 good (though not cartographic) quality images.

Use of the high gain tracking antenna on free-flying balloon was proposed studied at the Venus Multisonde Mission [23]. Robustness of the Titan airship material may allow to locate the antenna inside the airship hull that may significantly benefit to the system design. Combined action of the antenna's and airship's motors can be used for tracking.

Higher transmitter power (facilitated by efficiency of cold atmosphere), use of Ka-band and/or orbiter relay are possible methods to increase the data rate.

Navigation is needed for trajectory control and to locate the source of the acquired data. The usual magnetic compass can not be used on Titan since it has no significant magnetic field. A combination of sources can be used for navigation of the airship. Among them are: Doppler, range and VLBI measurements from the Earth; Doppler and Radio Direction Finding (RDF) measurements from the orbiter; on-board of aerobot measurements of direction to celestial sources—to the Sun (in absorption-free bands – optical, infrared and RF), to the Earth (RDF of DSN beacon), Saturn or to the orbiter. Inertial Measurement Unit (IMU) that is set up to the known position prior to the atmospheric entry can be used for navigation at the beginning of the atmospheric flight; it should be corrected regularly by exterior sources.

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8. INITIAL TESTS

Two concepts of the Titan airship are developing and testing under the NASA Cross-Enterprise Technology Development Program. One is traditional airship with the ballonet vertical control, another - "aerover" with the capability of landing and alternative vertical control.

Aerial deployment and inflation is the common technology that should be developed for both concepts. The technology is leveraged on success of tropospheric deployment in Mars Balloon Validation Program (Kerzhanovich et al, 1999). Deployment of a streamlined airship introduces a number of new factors – packing, load transfer, mass distribution, direction of the deployment, necessity of configuration changes to steady flight attitude etc.

First tests at the vertical wind tunnel at the NASA Langley Research Center (Fig.6) brought encouraging

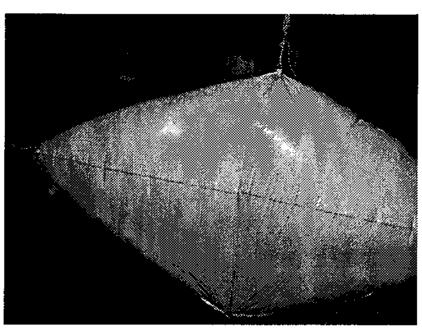

Figure.6. Streamlined hull during inflation in wind tunnel

results enabling deployment and inflation of the airship along the short axis. Flight tests are scheduled for this year. If successful would significantly simplify the airship system design.

Initial testing of Aerover concepts has begun with materials research and scale-model Aerover mobility tests. The first Aerover model tested was a commercially available one-meter blimp that was modified to allow surface mobility (landing wheel added), operation as a partially deflated zero-pressure vehicle (plastic nose battens added), and heat-activated altitude control (black patch added to absorb external radiant heat). The model exhibited excellent control both in the air and on solid surfaces. Altitude variations were fully controllable by engine fan thrusts, by radiant heat input (ascent), and convective cooling (descent).

A larger, six-meter commercially available blimp has is being modified for testing as a Titan Aerover (Figure 7). A landing floatation wheel has been added that will allow testing on solid land as well as on liquid lakes. The engines are rotatable to allow powered ascent, and a section of the upper blimp body will be blackened to demonstrate zero-pressure heated ascent using solar heat, instead of RTG heat. All mobility test results will be compared with theory to ascertain accurate mobility and thermal models.

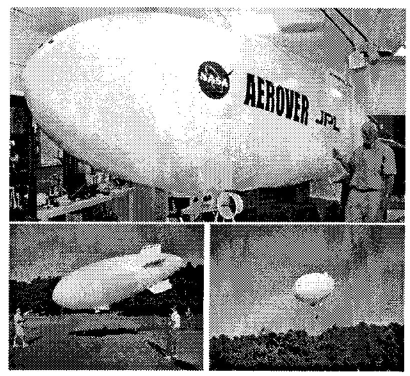

Figure 7. Aerover tests

9. SUMMARY

The proposed concept of a Titan Explorer is a relatively low-cost mission with both high scientific and technological return providing accurate measurements of the Venus atmosphere from the surface to 80-82 km and validating key technologies that will be need for much more expensive and much more visible Venus Surface Sample Return Mission.

10. ACKNOWLEDGEMENTS

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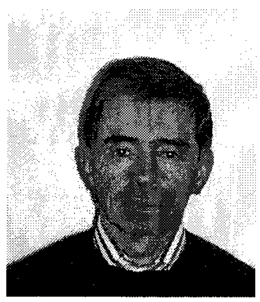
12. BIOGRAPHIES

Jeffery L. Hall *received his B. A. Sc. (Hons.) degree in Engineering Science from the University of Toronto in 1984, and M. S. and Ph. D. degrees in Aeronautics from the California Institute of Technology in 1985 and 1991 respectively. He joined the Jet Propulsion Laboratory in 1997 where he has worked on a variety of technology development and mission design projects including planetary balloons, Venus atmosphere probes and landers, aerocapture vehicles and cryogenic refrigeration. Dr. Hall is a Senior Member of the AIAA.*



Viktor V. Kerzhanovich *received his B.S. in physics from Moscow State University, Candidate of Science degree and Doctor of Science in physics from the Space Research Institute of the Soviet Academy of Sciences, Moscow. He took part in atmospheric experiments, tracking and data acquisition on all Soviet deep space probes to Venus and Mars, including Venera 4-16, the VEGA, and Phobos. In 1997 he joined the Jet Propulsion Laboratory/ California Institute of Technology as a Senior Member of Technical Staff. Since then, his efforts have been concentrated on development of aerobot technology for planetary applications. His technical interests include scientific ballooning, communication, tracking and navigation. Dr. Kerzhanovich has published over 100 papers on technology applications, mission concepts and planetary studies. He is a member of AIAA Technical Committee on Balloon Technology.*

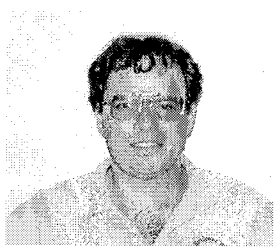
Jack Jones *received his BSME from Rutgers University and his MSME from Rice University. He has been with JPL since 1979 and is presently a Principal Engineer and Member of Technical Staff. He has published over 140 papers on heat transfer and mobility systems, holds 22 patents, and has received numerous awards. He is presently the task manager for "Inflatable Technology for Robotics" as well as for "Planetary Balloon Buoyancy Systems", which is studying balloon missions for seven atmosphered planets plus Titan.*

James A. Cutts *is Deputy Manager of the Mars Exploration Office at the Jet Propulsion Laboratory. Prior to his current assignment, he was Program Manager for the Special Projects Office, where he most recently led the initiative in Planetary Aerobots or robotic balloons for planetary exploration. Prior to joining JPL, he directed the Planetary Science Institute of Science Applications International Corporation in Pasadena, California and participated in the scientific investigation teams for the Mariner 9 and Viking missions to Mars. He has served as Chair of NASA's Sensor Working Group and has been a member of other NASA and U.S. Air Force advisory committees. He holds a B.A. in Physics from Cambridge University, a M.S. in Geophysics and a Ph.D. in Planetary Science from Caltech, and a Certificate from UCLA's Executive Management Program. He has authored approximately 50 papers in planetary science, sensor technology, and innovative space mission concepts.*

Andre H. Yavrouian *received his M.S. in Organic Chemistry and Polymers from Sofia State University, Sofia, Bulgaria. In 1977 he joined JPL and since 1990 has been Group Supervisor of the Analytical Chemistry & Material Development Group. His recent involvement includes evaluation, characterization, qualification and testing of materials for planetary balloons, ballutes and inflatable planetary rovers and development of sterilization concepts for Mars Sample Return. Flight project involvement includes area of propellants chemistry, materials selection, materials compatibility and testing for Cassini, Wide Field Planetary Camera, Mars Observer, Galileo and other spacecrafts.*

Past years involvement includes synthesis and development of carbons for sorption cooling, polyurethanes for electronic part encapsulation, artificial blood substitutes, fuel additives to suppress post-crash aircraft fires, polymerizable UV absorbers for solar cell encapsulation and others. List of publication includes over 80 papers, scientific reports and patents.

Anthony Colozza *has a bachelors (87) and Masters degree (89) in aerospace engineering from the Pennsylvania State University. He has worked at the NASA Glenn Research Center as a support* *service contractor for the last 12 years as well as with a small engineering consulting firm for the last 2 years. Throughout this time he has worked on a number of projects related to high altitude aircraft propulsion and power system operation and planetary flight vehicles. He has relevant work experience in the following areas; aerodynamics, power and propulsion systems, aircraft design and propeller analysis and design. Some of the projects he as worked on include: the design and construction of a solar powered aircraft, high altitude solar powered aircraft analysis, manager of the propulsion system development for the proposed Mars 2003 aircraft program, propeller analysis for high altitude aircraft and principal investigator on evaluating the potential of producing an entomopter for flight on Mars. Through these projects he as published more the 25 technical papers and holds one US patent*



***Ralph Lorenz** is a Senior Research Associate in the Lunar and Planetary Lab at the University of Arizona. He has a B. Eng. in Aerospace Systems Engineering from the University of Southampton and a Ph.D. in Physics from the University of Kent, both in the UK. He worked for the European Space Agency at ESTEC, Noordwijk, The Netherlands on the payload of the Huygens spacecraft destined for Titan. He is presently involved in NASA's largest planetary flight project Cassini (as a member of the RADAR team and a co-Investigator on the Huygens Surface Science Package). He delights in doing both planetary science and spacecraft engineering.*